Spatial time resolution of MCP–PMTs

as a time reference with up to sub-4 picosecond precision

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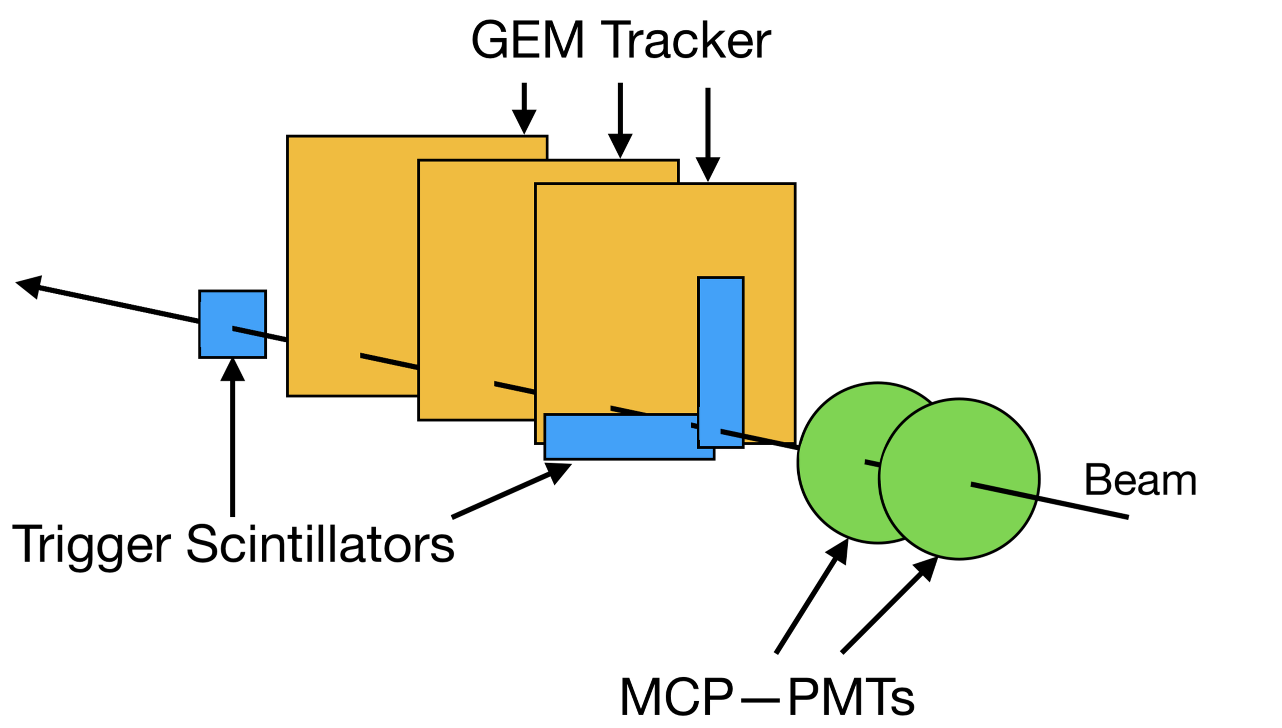
On behalf of the PICOSEC collaboration

1 – Motivation

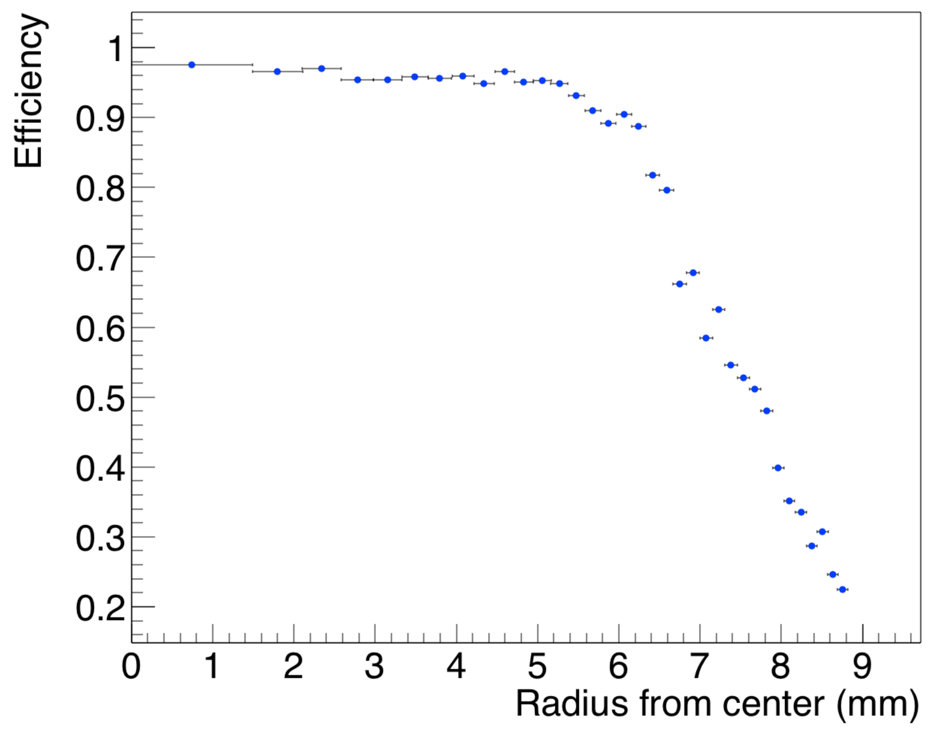
- Verification of the MCP–PMTs (R3809U-50 by Hamamatsu) as timing reference in beam tests.
- Measurements done during muon beam tests of PICOSEC Micromegas [1] at CERN SPS/H4.
- The spatial distribution of the time resolution defines the effective usable active area.

2 – Beam Set-up

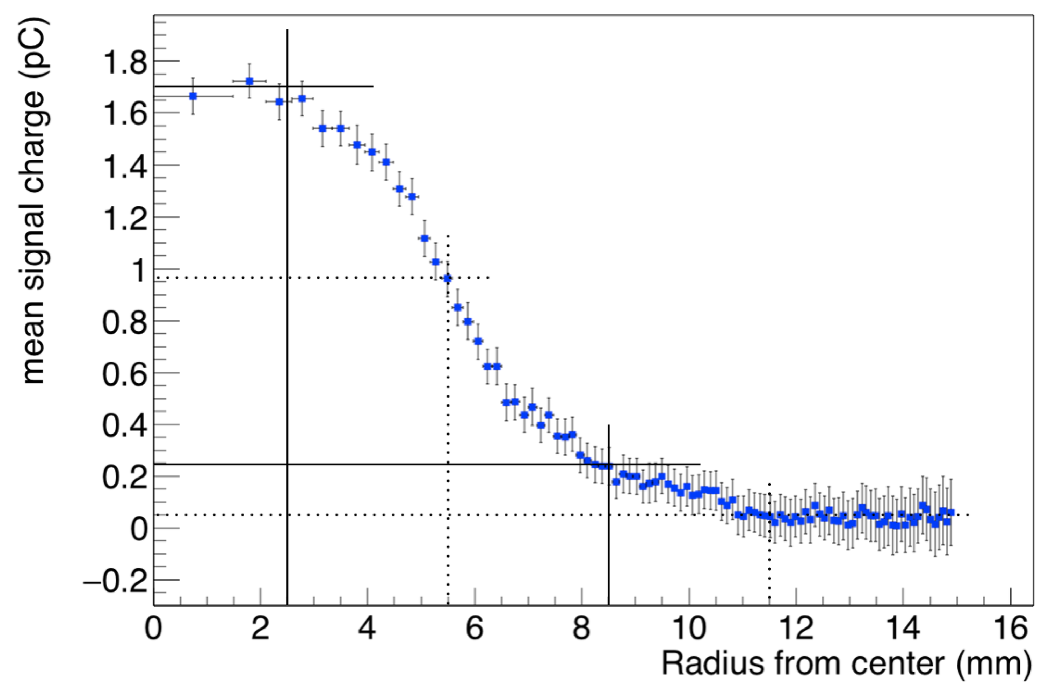
- Two MCP–PMTs has been operated in parallel.
- Beam telescope has been used in a muon beam.
  - Three triple GEM with strip segmented anode have been used to reconstruct tracks of inclining particle.
  - Coincidence read-out logic of different shaped scintillators are forming a trigger signal.
- Full MCP–PMT signals have been acquired by an oscilloscope (20 GS/s) for an offline analysis.



3 – Efficiency

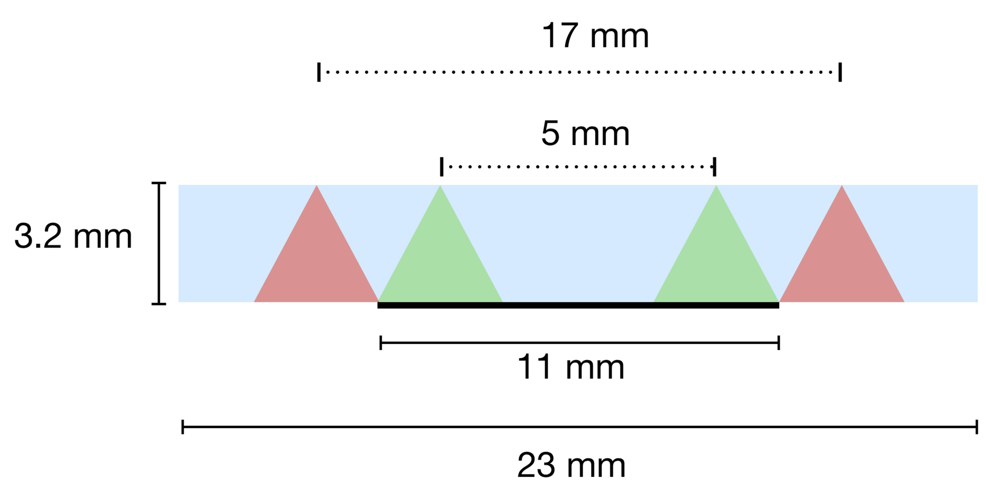


4 – Mean Signal Charge



- MIPs are detected in a Cherenkov radiator and the Cherenkov light is converted to electrons in a photocathode.
- The signal charge depends on the number of primary electrons created in the photocathode.
- Less electrons are formed, when the Cherenkov cone is partially projected on the photocathode.
- The dimension of the photocathode and the Cherenkov window can be determined out of the radial distribution of the mean signal charge.

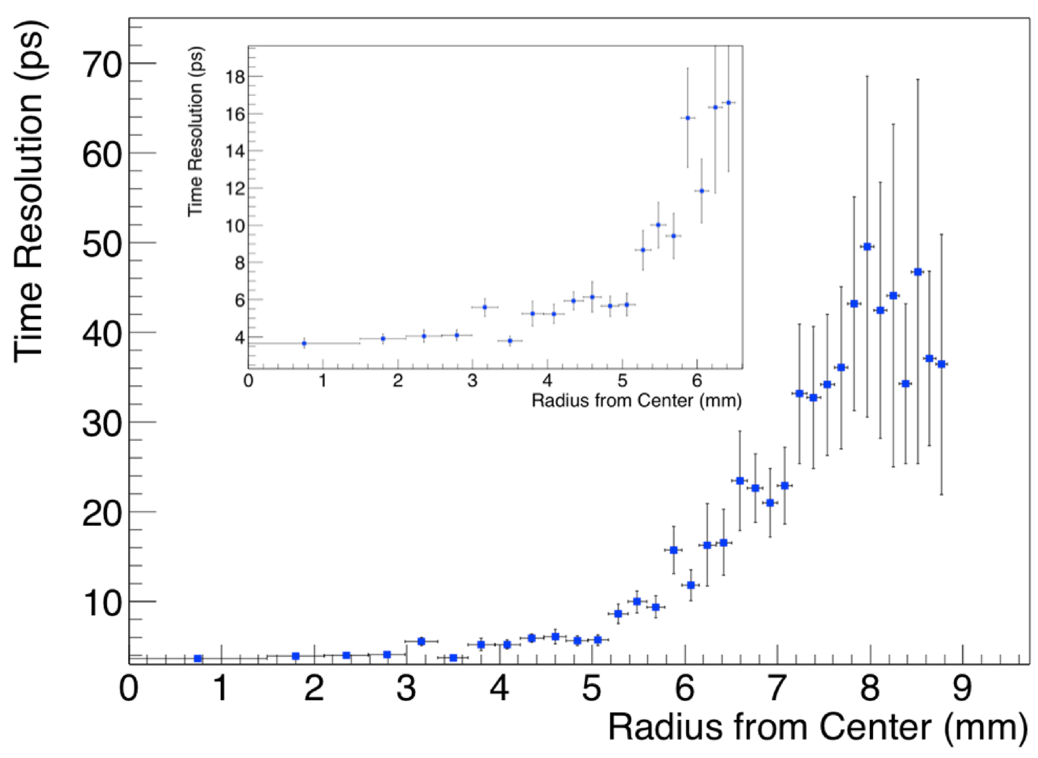
5 – Light Cone Projection



There are three regions with different behaviour of the Cherenkov light cone projection onto the photocathode:

- **Full Signal:** The light cone is fully projected onto the photocathode.
- **Partial Signal:** The cone is partially projected. Decreasing with higher radii from the centre.
- **Reflected Signal:** The particle is hitting the Cherenkov window further outside and only multiple reflected light reaches the photocathode.

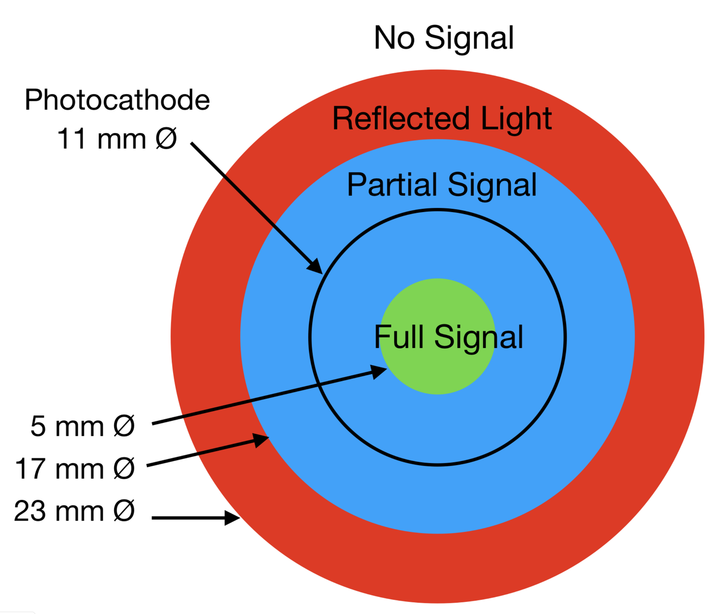
6 – Time Resolution

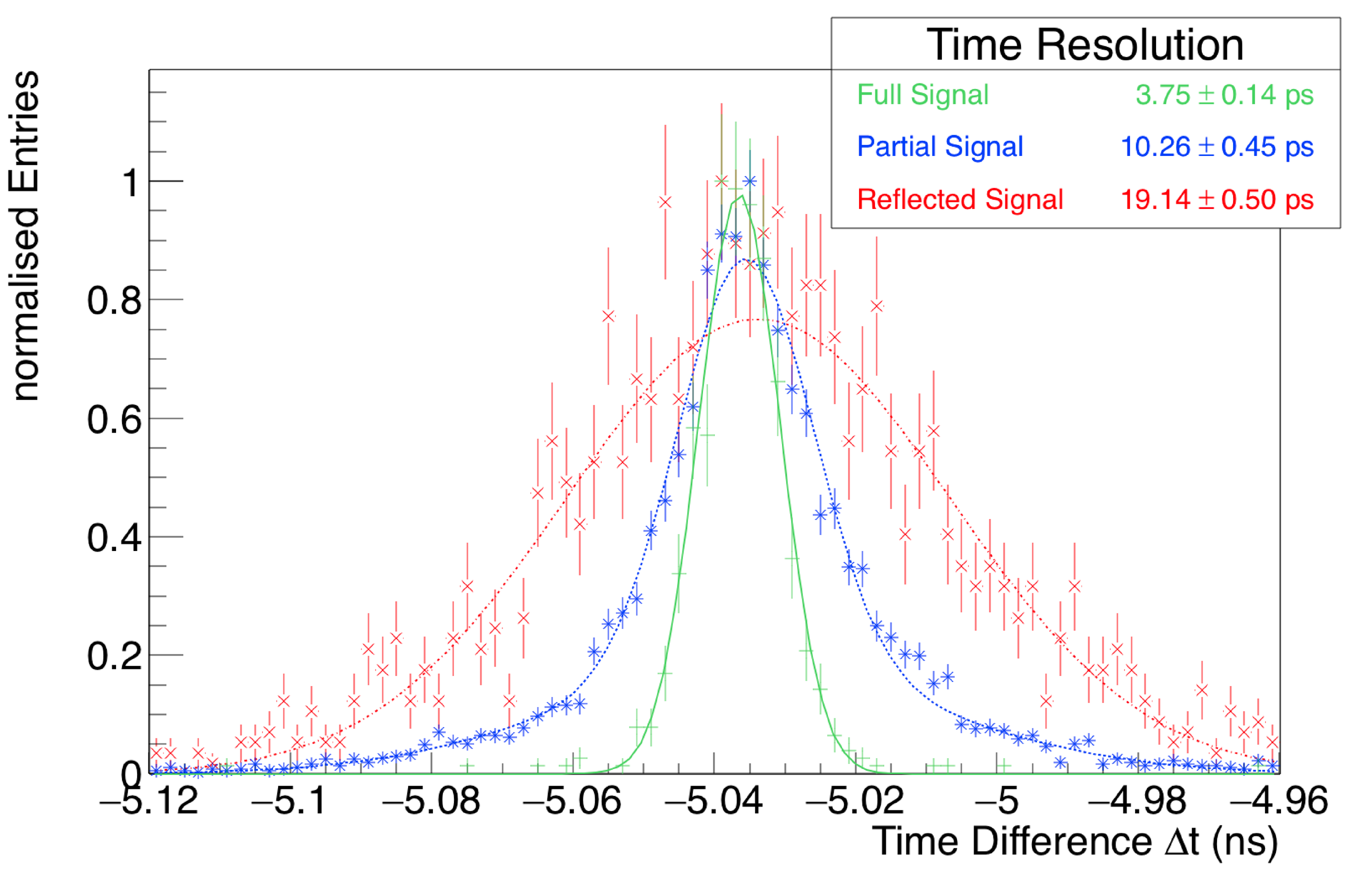


- The time difference between the two MCP–PMT signals follow a Gaussian distribution.
- Its standard deviation is related to the time resolution of each individual MCP–PMT by:

$$\sigma_{\text{tot}} = \sqrt{\sigma_1^2 + \sigma_2^2} \Rightarrow \sigma_{\text{TimeRes}} = \frac{\sigma_{\text{tot}}}{\sqrt{2}}$$

- The time resolution degenerates for particles hitting the detector in the outer regions. These project less light directly on the photocathode and the signal amplitude is smaller.





7 – Conclusions

- The MCP–PMT is useable as a timing reference over the whole area of the photocathode (11 mm ⌀).
  - The time resolution is under 6 ps and the efficiency is over 95 %.
  - In the outer parts the time resolution reaches the same order of magnitude as the DUTs.
  - The best time resolution can be achieved when the light cone is fully projected.
- A power divider can be used to distribute two oscilloscopes with the same reference signal.
- A reduced sampling frequency has an impact on the fast rising edge shape and the time resolution.

8 – References

1. Bortfeldt, J. *et al. PICOSEC: Charged particle timing at sub-25 picosecond precision with a Micromegas based detector. Nucl. Instrum. Meth.* (2018). doi: 10.1016/j.nima.2018.04.033.
2. Inami, K., Kishimoto, N., Enari, Y., Nagamine, M. & Ohshima, T. *A 5-ps TOF-counter with an MCP-PMT. Nucl. Instrum. Meth.* **A560**, 303–308 (2006). doi: 10.1016/j.nima.2006.01.027.
3. Sohl, L. *Beam Measurements of PICOSEC Gaseous Detectors for Fast-Timing Applications* Master's Thesis (Ruhr-Universität Bochum, Germany, 2018).